New Features of HYCOM

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16th Layered Ocean Model Workshop

May 23, 2013

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
23 MAY 2013		**00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
New Features of HYCOM	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,1 Stennis Space Ctr ,Stennis Space Center,MS,39529**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Layered Ocean Model Workshop, Ann Arbor, MI, 21-23 May 2013.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**17**	

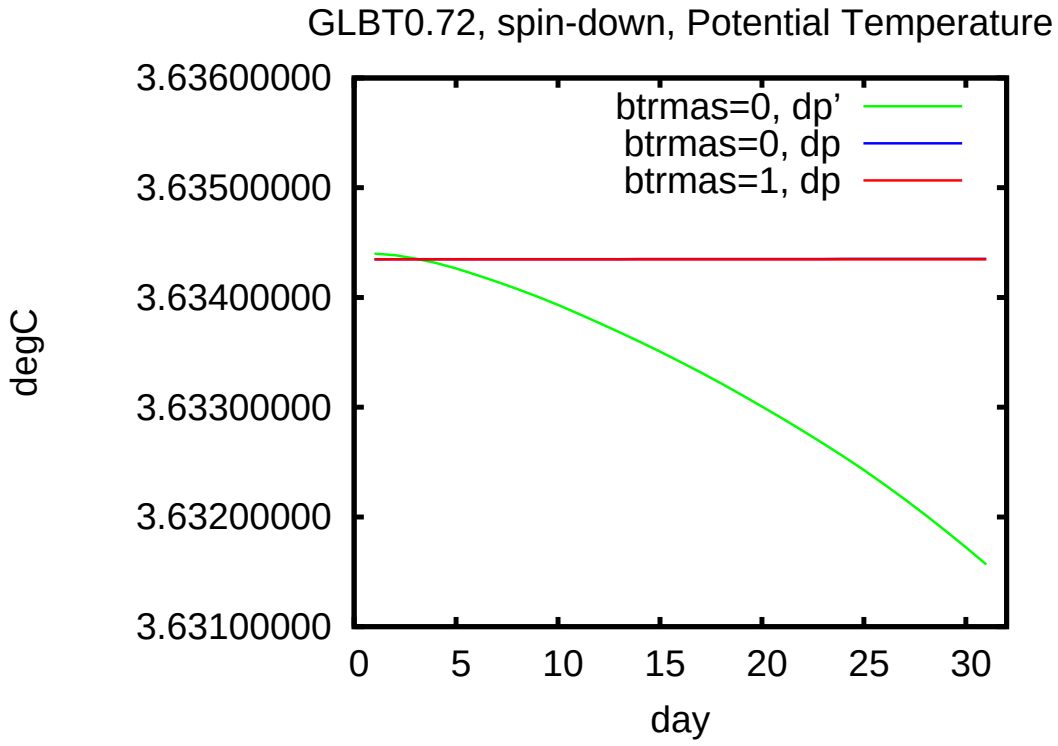
Mass Conservation - I

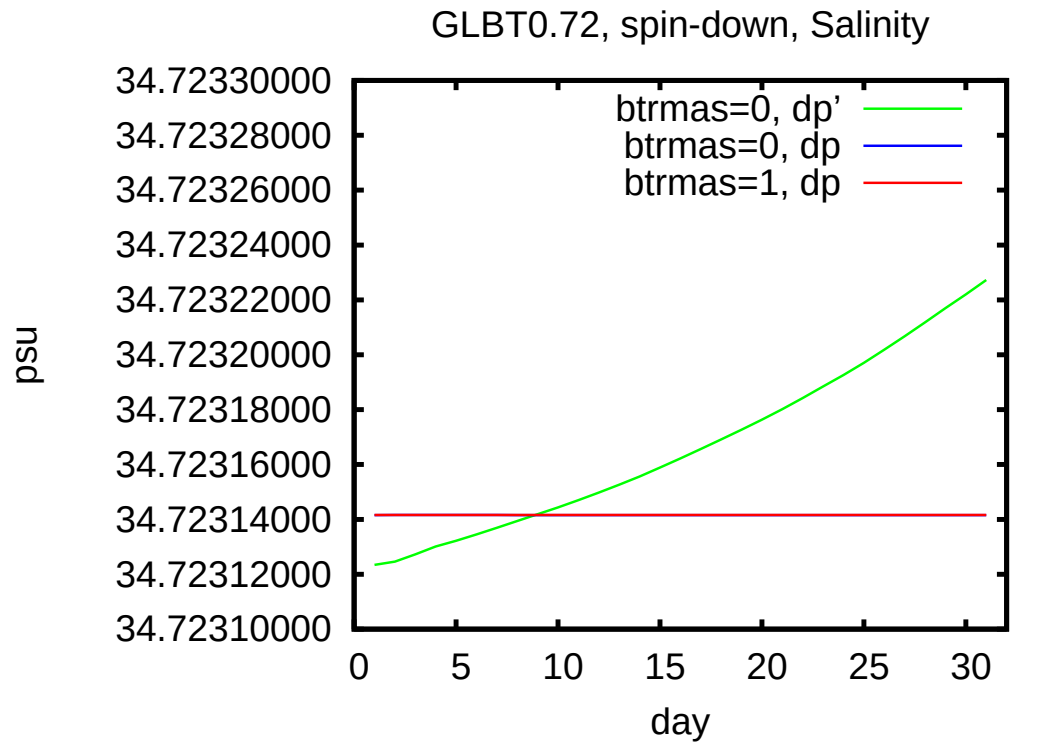
- Mass conservation is important for climate studies
  - It is a powerfull debugging tool even for shorter time scales
- Many ocean models are Bousinessq
  - Density differences are neglected except in terms multiplied by g
  - Implies conservation of volume, not mass
    - Still want, and can get, tracer conservation
- HYCOM is not Bousinessq, so it should conserve mass
  - Except that it assumes the non-steric SSH is a small fraction of the total depth
    - Includes steric effects, such as mean SSH rise due to thermal expansion, but does not exactly conserve either mass or volume
    - Not satisfactory for coastal domains
  - Replaces dp with dp’ nearly everywhere

Mass Conservation - II

- HYCOM's reputation for non-conservation is partially due to using dp' in mean calculations
  - Much better conservation properties when correctly using dp in region-wide means
  - HYCOM source code uses dp' for means, i.e. this is a long standing "bug"
- New option, btrmas=1, for exact mass conservation
  - From Remy Baraille at SHOM
  - Removes the dp' "equals" dp approximation
  - Note that dp' is still the prognostic variable
    - Still dp' in restart and archive files
  - Currently, btrmas=1 is less stable than btrmas=0
    - Still working on making it more stable
- As a test, 0.72° Global HYCOM was spun-up for 5 years with typical atmospheric forcing and then all forcing was removed
  - During "spin down" there should be no change to the total heat and salt, i.e. to the mean T and S

Spin Down Test of Conservation - I





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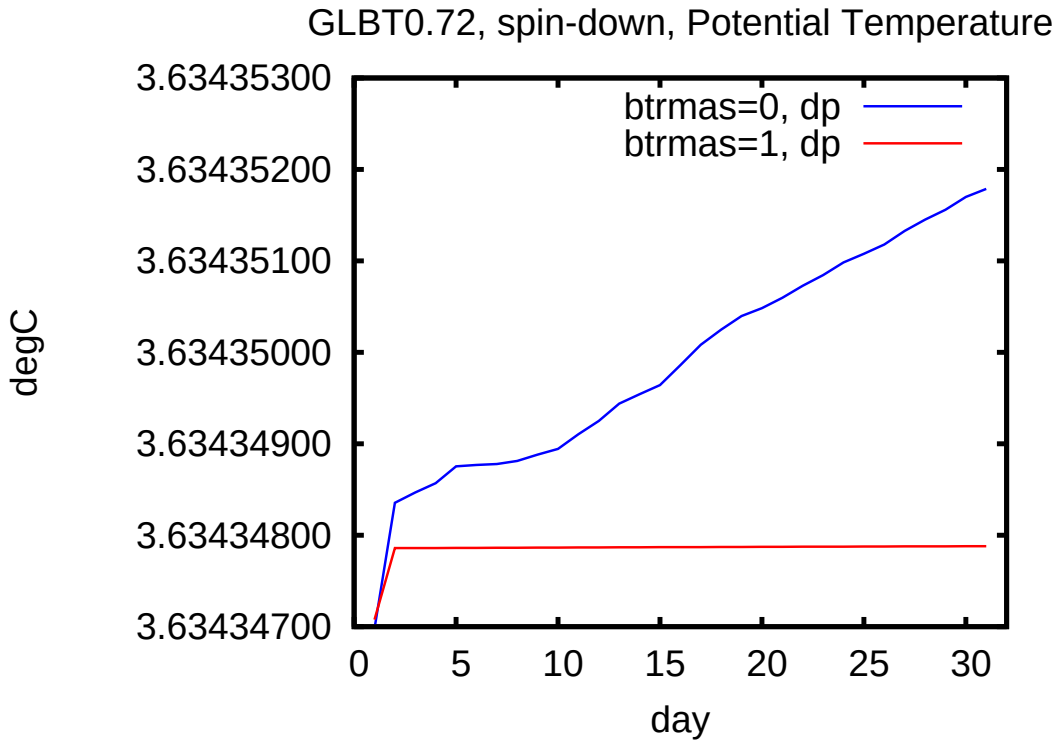
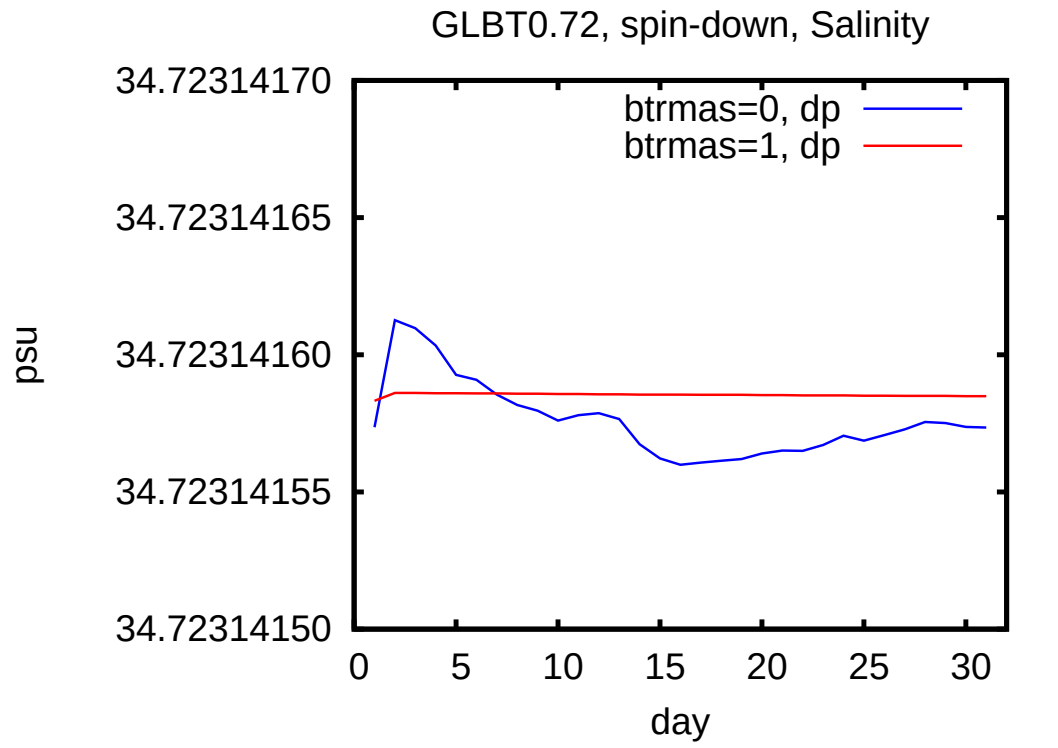
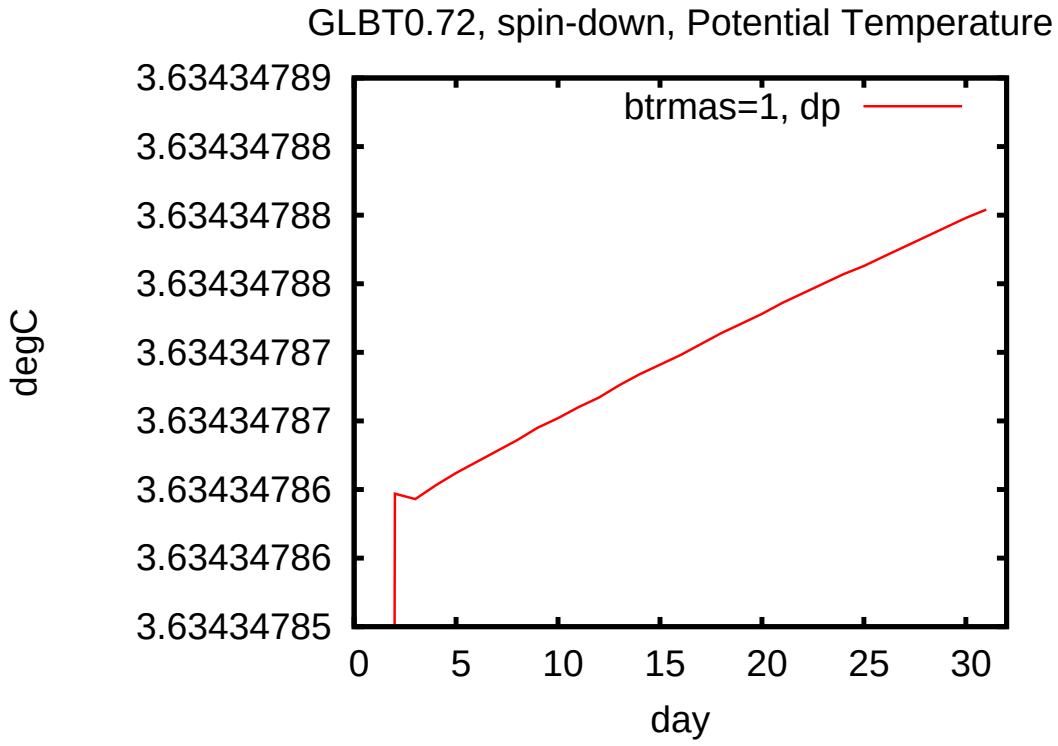
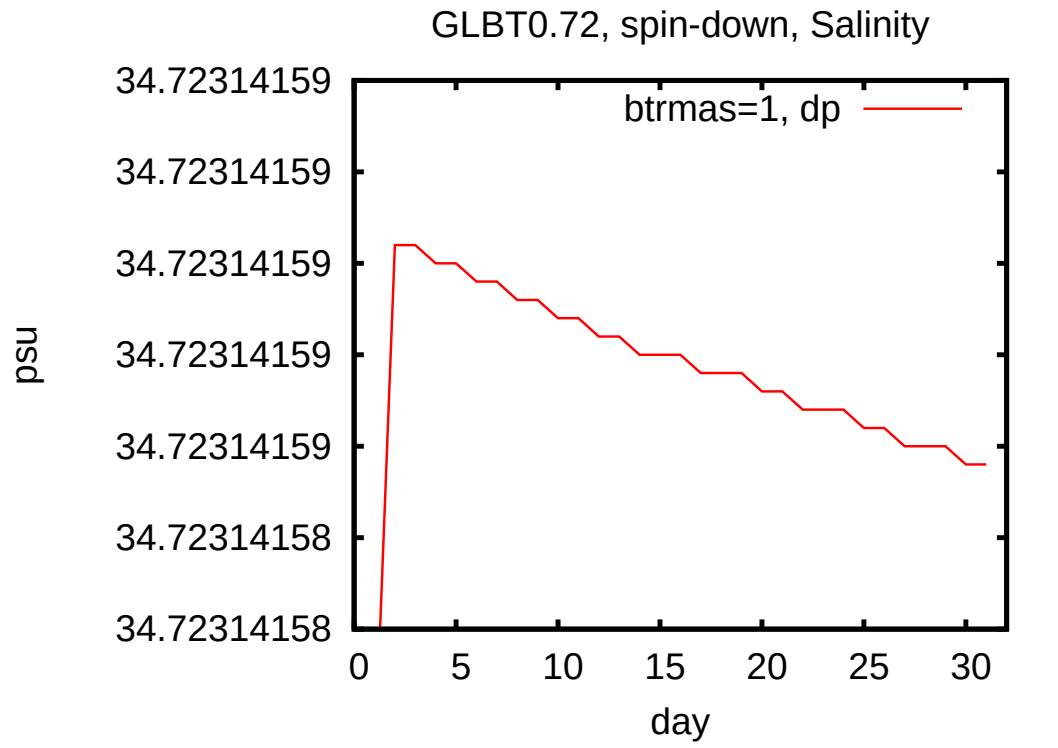




Spin Down Test of Conservation - III





Robert-Asselin Time Filter

- One potential source of non-conservation is the RA filter used to stabilize the leapfrog time step scheme
  - Williams (2009) proposed a modified filter that is more conservative and more accurate
    - However, it is not applicable to models with time varying layers than must filter h and hC consistently while maintaining non-negative fields
- Leclair and Madec (2009) showed that RA is:
  - Conservative without surface forcing
    - As demonstrated numerically by spin-down case
  - Can be made conservative if surface forcing terms are calculated at half time steps
    - Implies no time splitting from forcing
    - Explicitly remove forcing from RA filter
- HYCOM is not currently conservative with surface forcing
  - Started testing Leclair's approach

Bit-for-Bit Multi-CPU Reproducability

- Repeating a single processor run:
  - Produces identical results
- Repeating a multi-processor run:
  - Produces different results
    - Using either OpenMP or MPI
    - e.g. fastest global sum is non-reproducable
  - Unless programmer explicitly avoids non-reproducable operations
    - May need to avoid some compiler options
- Two levels of reproducability
  - On the same number of processors
    - Some scalable libraries provide this
  - On any number of processors
    - Only “safe” option for code maintenance
      - Always requires carefull programming
      - Can be slower
    - Should be required for operational ocean prediction models
      - Is implemented by HYCOM

Are Two HYCOM Runs Identical? - I

- The only way to comfirm bit-for-bit identity is to compare binary fields
- Could compare binary archive and/or restart files
  - But these don't tell you where any differences came from
- P-MICOM used "named pipes" to compare arrays between MASTER and SLAVE model runs while they were in progress
  - A named pipe is a special Unix file providing a FIFO capability via a shared memory buffer
  - Can read and write to it just like a normal file
- SLAVE writes an array to the pipe, MASTER reads the array and compares it to its own version
  - Usually MASTER runs on one processor and SLAVE on multiple processors
  - Only limitation is that MASTER and SLAVE must be running under the same Unix image
    - May be difficult to arrange for MPI on a cluster

Are Two HYCOM Runs Identical? - II

- HYCOM includes a named pipe based comparitor
  - Similar to P-MICOM, but easier to use
  - Calls to compare or compareall in source code:
    - Can trigger a comparison of arrays at run time, between two HYCOMs via the named pipe
    - Can invoke other run-time debugging options
- A new option is to compile with the OCEANS2 macro
  - Runs two instances of HYCOM in the same executable
    - Each on a different number of MPI tasks
  - Calls to compare or compareall in source code:
    - Will trigger a comparison of arrays at run time via MPI send/recv
  - Easier to use than named pipes and only requires MPI
    - Works for OpenMP with MPI, but same number of threads used by both HYCOMs
    - Does not currently work in coupled models

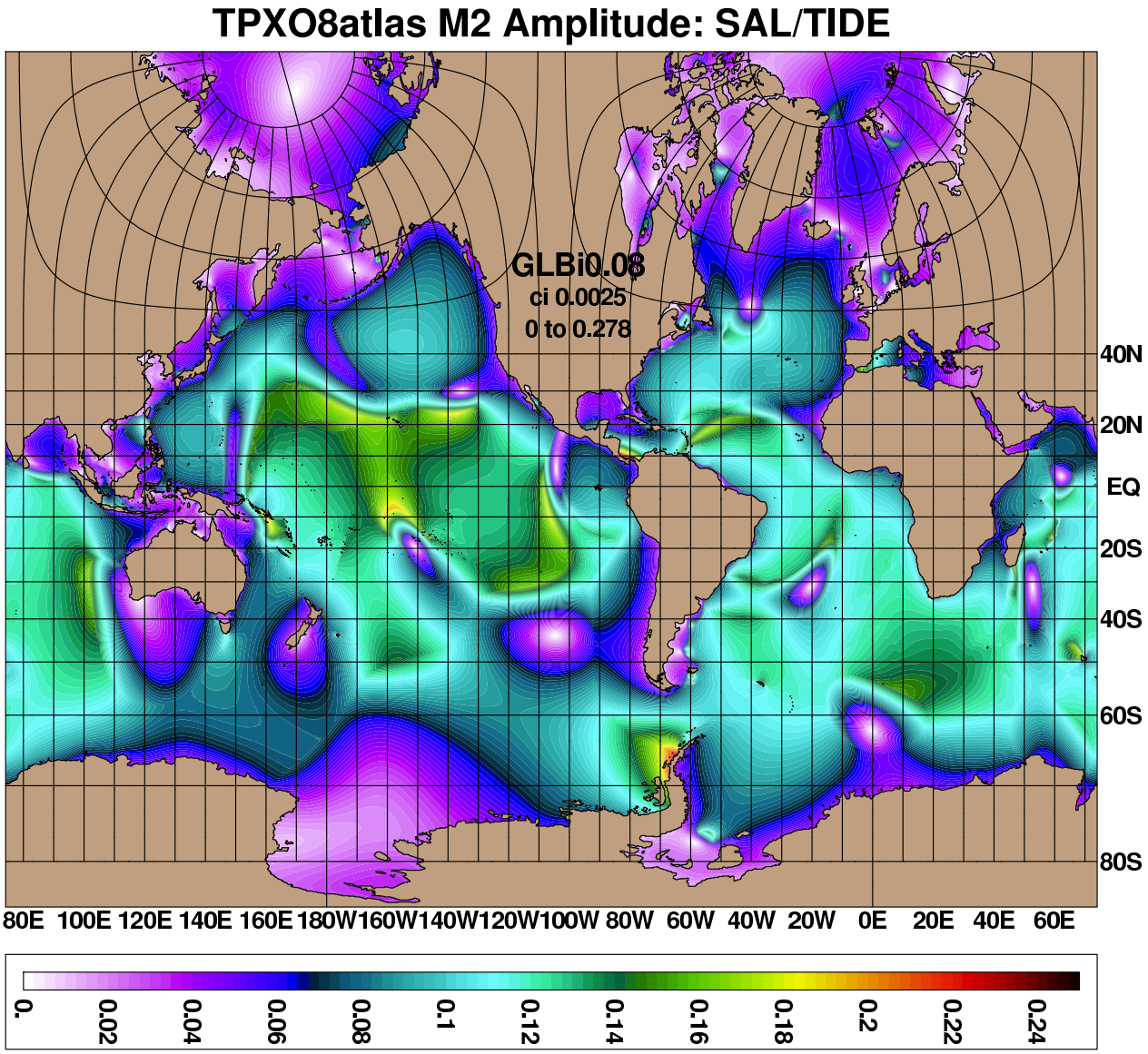
Tides in HYCOM - I

- Body forcing for 8 largest components
  - With (optional) nodal corrections
  - Implemented in HYCOM by NCEP
- Boundary forcing for Flather or Browning-Kreiss ports
  - Implemented by various groups in local versions of HYCOM
  - Now in standard version
    - 8 largest components specified as complex amplitudes at each boundary point using unmodified extract_HC program from OSU's OTPSnc or OTPS2 package
    - Allows for curvilinear grid
    - With (optional) nodal corrections
  - Tidal forcing under floating ice shelves requires 1147 ports for Global 1/12° domain
    - Port implemention updated to allocate memory at run time and to make many fewer MPI calls for better MPI performance

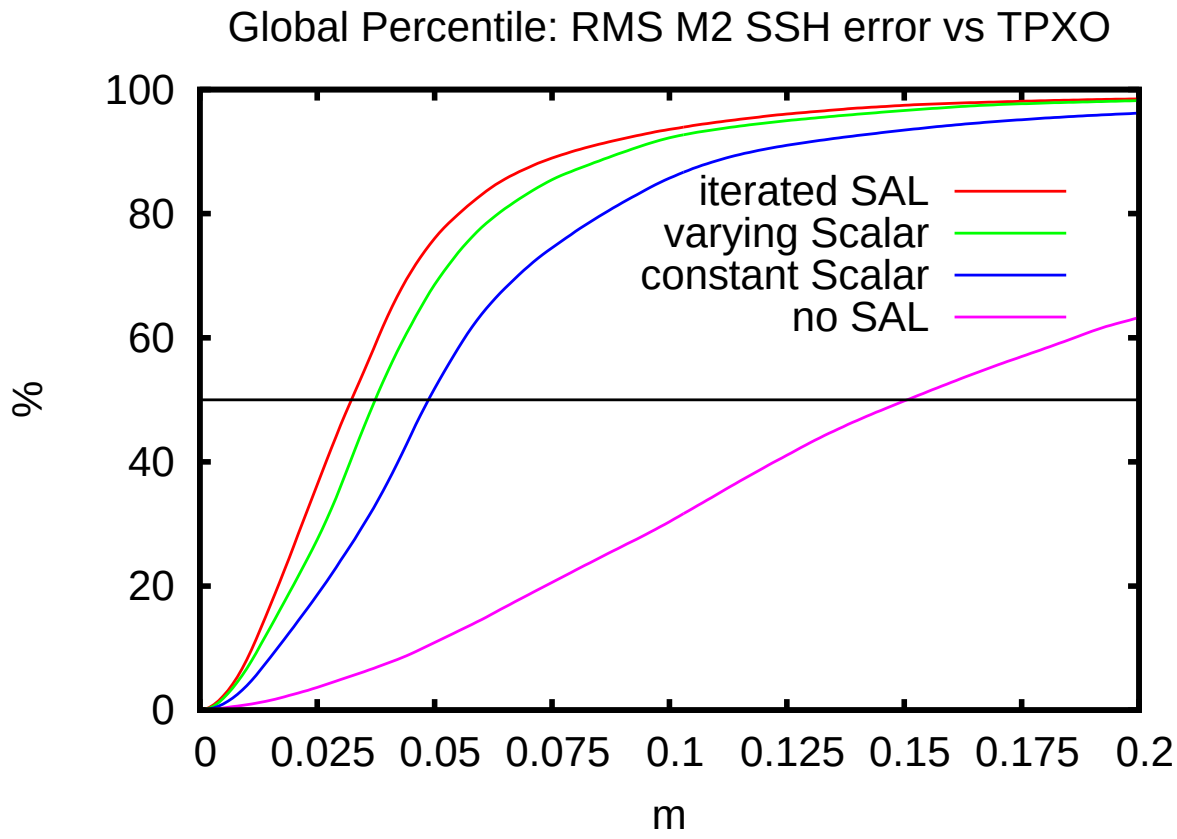
Tides in HYCOM - II

- Linear tidal drag based on bottom roughness
  - Applied to near-bottom tidal velocity or to depth averaged tidal velocity
    - Tensor drag for depth averaged case only
  - Use a lagged 49-hour filter as the non-tidal velocity
    - Convolution of a 21 hour Savitzky-Golay smoother and a 24.842 hour boxcar filter
    - Passes 0.02% of semi-diurnal and 3.2% of diurnal (1.2% of total) tides
      - Replaces a lagged 25-hour average
      - Better band pass and better diurnal phase
  - Limit drag's e-folding time for stability
- Self Attraction and Loading
  - "Scalar" approximation:
    - SAL treated as a fraction of non-steric SSH
      - Constant, or spacially varying, fraction
  - Input SAL complex amplitude fields from a file
    - With or without a "scalar" SAL
    - Iterate SAL to convergence

Spacially Varying Self Attraction and Loading



Self Attraction and Loading Comparison



- Barotropic Global 1/12° M2-only simulations
  - Twin cases that differ only in Self Attraction and Loading
- The percentage of the globe (Y) where model - TPXO8atlas SSH RMS is less than X m
  - Note the long tail with the median (50%), for the with-SAL cases, between 3 cm and 5 cm
    - Median is typically a more robust statistic than mean or global RMS

Tides in HYCOM - III

- Several tide-specifc diagnostic programs:
  - hycom_tidal_foreman
    - Foreman tidal analysis on HYCOM .a file
    - HYCOM's 4096-word blocking allows strip-mined transpose from (x,y,t) to (t,x,y)
  - hycom_calcSAL
    - Calculate SAL on uniform cylindrical global grid
  - hycom_tidal_rms
    - RMS difference between two sets of tides
  - hycom_tidal_ap2ri and hycom_tidal_ri2ap
    - Amp,Phase to/from Real,Imaginary tidal components
- Tidal analysis enabling output:
  - HYCOM SSH has mass and steric anomalies
  - Steric SSH can optionally be output
    - Steric anomaly plus long term SSH mean
    - Explicitly "filters" external tides
    - Get internal tides from Foreman tidal analysis
  - Non-steric SSH from difference
    - Largely external tides

HYCOM and Sea Ice

- Two-way coupling to LANL's CICE sea ice model, regional and global domains
  - HYCOM exports:
    - SST, SSS, SSH
    - Surface Currents
    - Available Freeze/Melt Heat Flux
  - CICE exports:
    - Ice Concentration
    - Ice-Ocean Stress
    - Actual Freeze/Melt Heat/Salt/Mass Flux
    - Solar Radiation at Ice Base
  - Coupling via the Earth System Modeling Framework
    - ESMF version 4.0.0rp2
    - Plan to migrate to NUOPC Layer on top of ESMF version 6.X.0r
- Coupled to CICE version 4.0
  - Version 4.1 was released in May, 2010
  - Plan to skip 4.1 and implement the "next release", due later this year

Coming Soon

- Wave forcing
  - Stokes Drift Current (SDC)
  - Wave-to-Ocean Momentum Flux (WOMF)
  - Bottom Orbital Wave Current (OWC)
- Wetting and Drying
  - Made possible by mass conservation option
  - Code from Remy Baraille at SHOM is already in HYCOM but needs more testing
- Fully region-independent
  - Compile once, run on any region and any number of processors
    - Run-time memory allocation, less memory used
    - Reduces performance
      - Compilers make fewer optimizations
      - Prototype is 5% slower
  - Needed for full ESMF compliance
    - Single executable, multiple components each running on separate cpus
    - HYCOM arrays currently on all cpus